U-BOLTS USED AS PIPE RESTRAINTS IN CANDU NUCLEAR POWER PLANT

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Abstract

In many existing cases U-bolts were used as pipe restraints. Restraining capacity and some physical properties were not known and/or properly understood while applied in the field. This created multiple problems.

Many U-bolts were applied in seismically qualified systems. Because manufacturers do not provide any stiffness values for loaded U-bolts that act as pipe restraints, it was necessary to develop dependable calculation method and arrive at results that would be used in seismic stress analysis. Without such input values seismic analysis is inaccurate. In this case re-analysing piping systems and achieving reliable Code compliant results was a problem.

Available capacity values provided by manufacturers created separate problem as they were found not dependable in everyday plant operation. Certain aspects of pipe restraining properties were not considered or given capacities were not trustworthy. Invariably it led to pipe support failures and urgent discovery work. In this case overloading U-bolts (with all attendant consequences) by using available capacity values was a problem.

To remedy existing unsatisfactory situation and develop dependable information and reference source, analytical work was initiated to gain full understanding of the situation when U-bolts are used as active pipe restraint. First part, including assessment of the U-bolt stiffness is already finished, while capacity assessment is in progress.

1.0 INTRODUCTION

In existing CANDU plants U-bolts were used extensively as the pipe restraints. They were used in the various situations and configurations. At the time of construction it was acceptable practice to install the "field run" nuclear class piping that met certain conditions. Of course the same was valid for the conventional (non-nuclear) piping. As a result there are many existing pipe restraints that utilize U-bolts as lateral, vertical, axial restraint or any combination of the above. There is whole group of the large size pipe supports (utilizing U-bolts) that were used in the seismically qualified piping. We need to operate plants with all the installed U-bolts and we must account properly for their presence. That means that we must be able to deal effectively with the maintenance (replacement), modifications and be able to analytically propose correct modification measures and realistically solve the causes of occurring U-bolt failures. There were two typical types of problems that we encountered. They are described in detail below.

2.0 SEISMIC PROBLEM

2.1 Existing Situation

Problem was to re-analyse piping systems and achieve reliable (realistic) and Code compliant results.

Any modifications and/or repairs of the seismically qualified piping systems that utilized U-bolts as restraints required repeat of the piping stress analysis. When conducting any seismic stress analysis it was impossible to use proper support (U-bolt) stiffness. Those values were (and are) not available from manufacturers. To complicate the situation even more quite frequently U-bolts were used together with beams and aggregate stiffness were misjudged even more by ignoring true physical properties of U-bolts as contributors in the combined support effect. Use of default values from pipe stress analyzing software was not satisfactory as they are usually set at about 5,000,000.00 lbf/in. This value is definitely many (more than 10) times higher than real value. This in turn led to analytical results that were not accurate and therefore not dependable (and in most cases would not pass the Code Check). Additionally, proper U-bolt stiffness values differ significantly in normal, lateral and axial directions and that fact must be taken into consideration as well as it plays significant role in stress analysis results.

2.2 Required results

Situation as described above is unsatisfactory and had to be remedied. Stiffness values for all three directions; normal, lateral and axial are required. They are necessary for the results of all stress analysis to be valid and meaningful.

2.3 Methodology

General method of getting answers to all our questions is Finite Element Analysis. Loads are applied to the accurately modelled U-bolts and required answers are acquired through the individual analysis of each one of them.

Initially only ALGOR models of the required U-bolt sizes were created. They were loaded in both normal and lateral directions by uniform loads that yielded results well in the elastic area. Computed displacements were used to calculate against known loads values of individual stiffness for analyzed U-bolts.

2.4 Present situation and future progress

When Piping Stress Report was being prepared it was noted that separate Calculation is required to report calculated U-bolt stiffness results. At the same moment decision was reached to extend the Calculation to include all U-bolt sizes to cover all future demands. This was done and official Controlled Document was issued with results. For graphical representation of load application method see Figures 1 and 2 below.

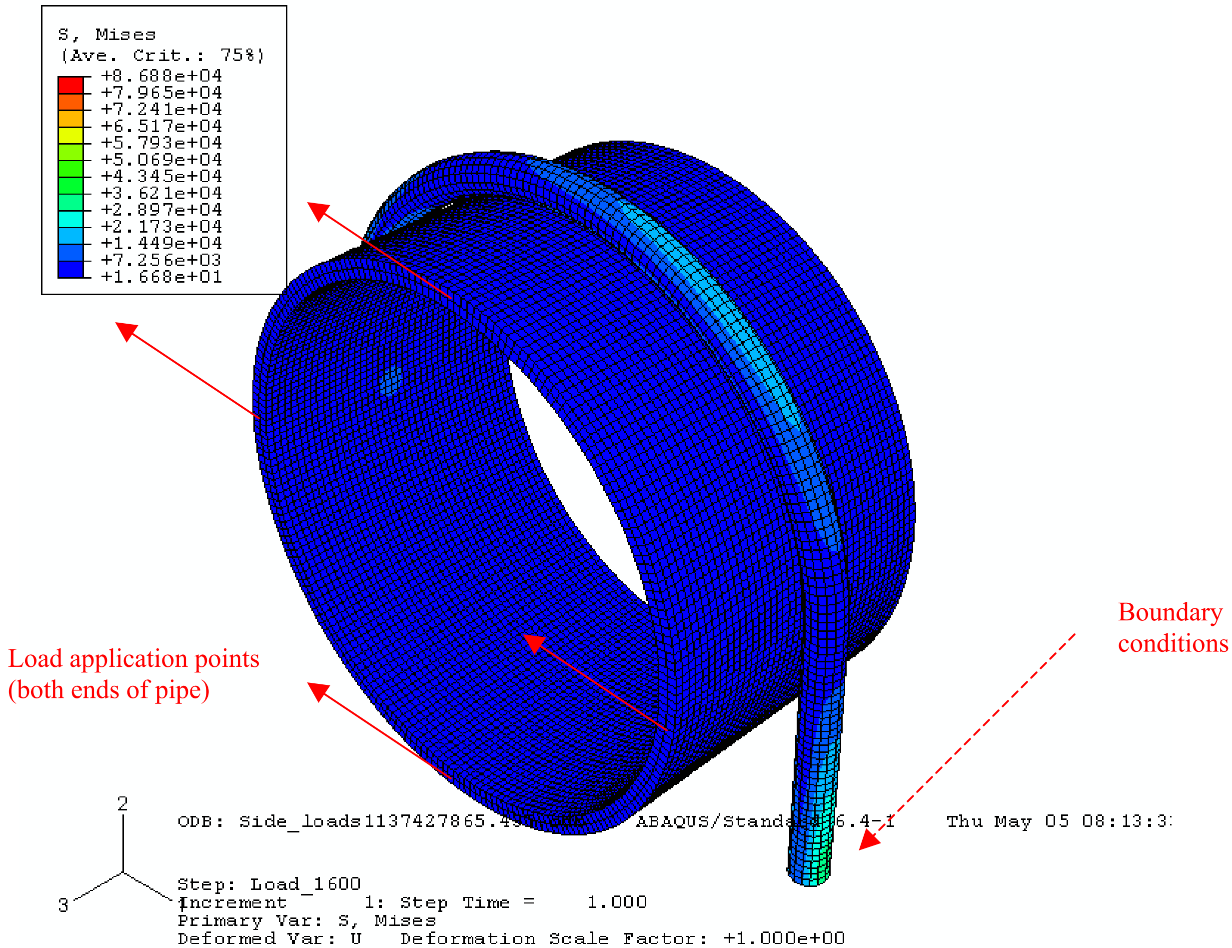

Figure 1 - Realistic side (lateral) load application

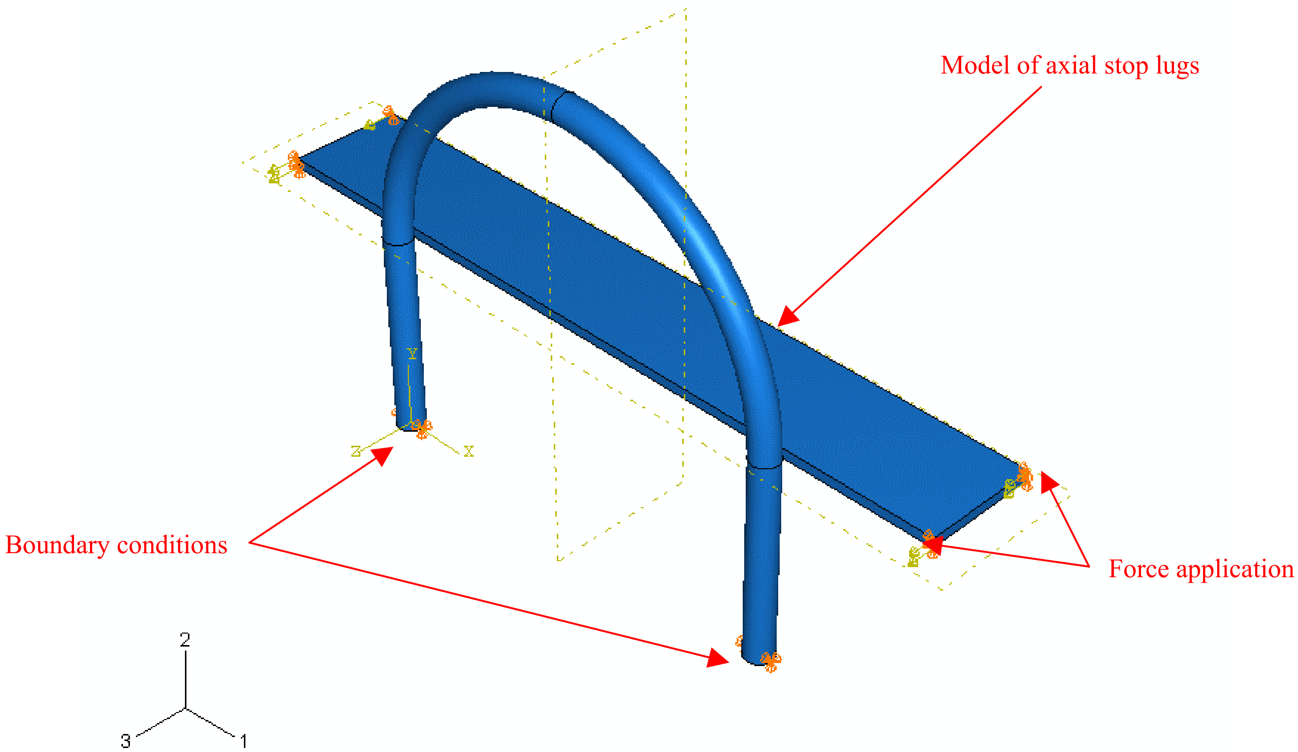

Figure 2 - Realistic axial load application

For examples of numerical results from our internal report see the Tables 1 and 2 below.

Table 1 - Lateral stiffness results (from issued report)

Pipe size [in]	U-bolt size [in]	Lateral displ. [in]	Lat. stiffness [lb/in]	Model [file name]
0.5	0.25	0.00073	4.11E+05	N0_5
0.75	0.25	0.00138	2.17E+05	N0_75
1	0.25	0.00218	1.38E+05	N1

Table 2 - Vertical stiffness results (from issued report)

Pipe size [in]	U-bolt size [in]	Vertical displ. [in]	Vert. stiffness [lb/in]	Model [file name]
0.5	0.25	0.00064	468.8E+3	N0_5
0.75	0.25	0.00088	340.9E+3	N0_75
1	0.25	0.00132	2.27E+05	N1

It must be noted that axial values were not included as they were not required at the moment of issuing the Report. Missing axial stiffness values will be calculated in the future and revision of the existing Report issued to make the stiffness set complete.

F. E. A. models of U-bolts of all commercially available sizes were prepared. Those models will be loaded by metal bar simulating axial stop lugs on pipe that are commonly used in that kind of support. For graphical representation see the Figure 2 above.

3.0 CAPACITY PROBLEM

3.1 Existing Situation

Problem was overloading U-bolts (with all attendant consequences) by using available capacity values.

We experienced multiple U-bolt failures (breaks or severe deformations). They had to be investigated and cause of damage found to prevent recurrence. Field experience and investigation results showed that U-bolt failure was caused by overload of the installed U-bolt. In many instances the design of pipe support utilizing U-bolt was "peculiar" as shown on the Figure 1 below.

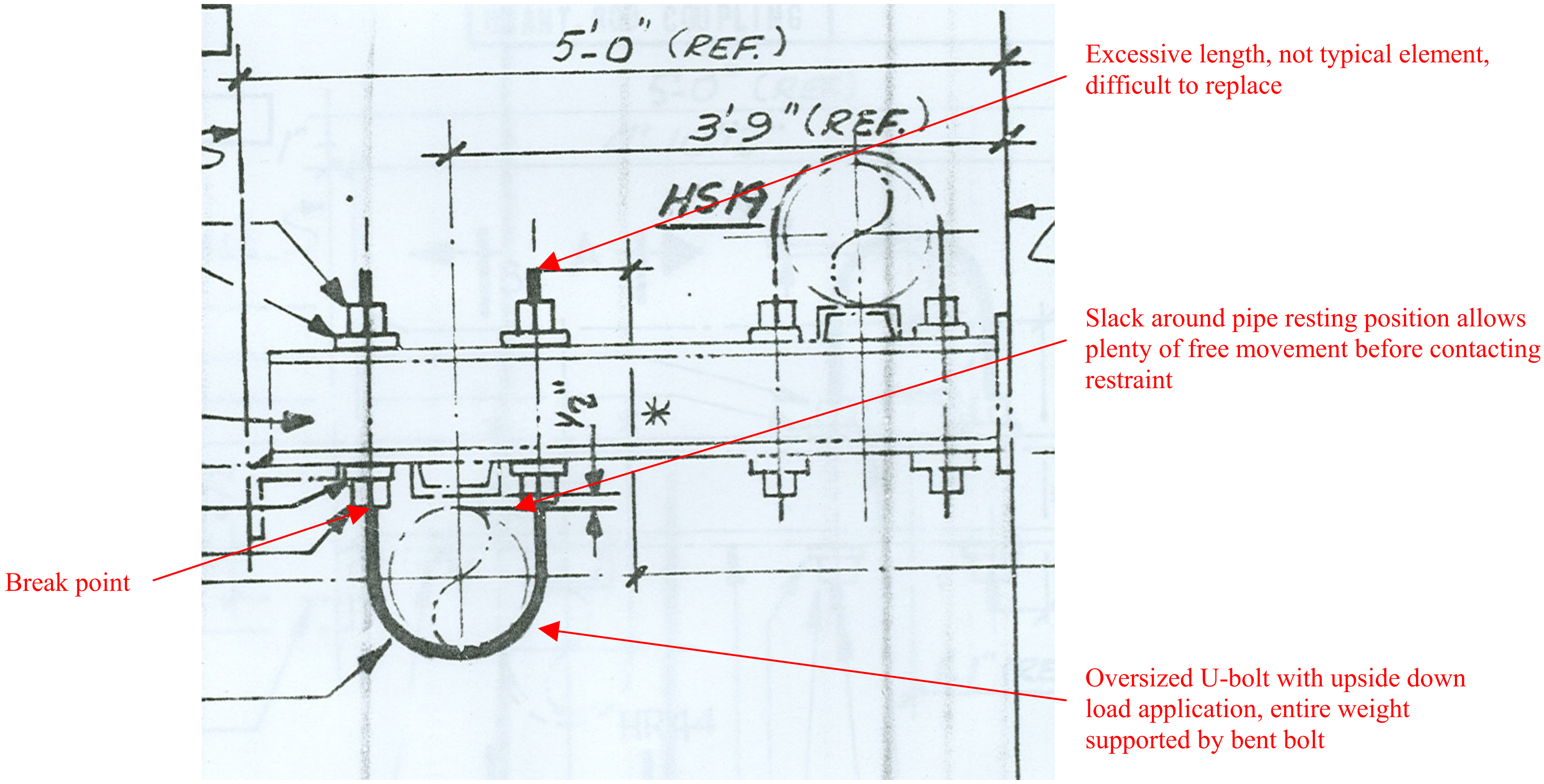

Figure 3 - U-bolt application example

This particular U-bolt was designed as oversized, inverted and only the vertical load was considered in the original design.

Photographs taken after the event showed following situation.

After its most recent failure, piping was analyzed and the U-bolt was assessed to be loaded sideways to the value described by the manufacturer as “allowable”. Bolt failed and one arm separated. Subsequent Finite Element Analysis that accurately modeled existent loads showed stress in excess of 86,000.00 psi. Similar situations were encountered in various systems and various supports. Capacity information about side and normal loads is not accurate and dependable and for axial loads is not existent. However normal maintenance practice is to use values provided by manufacturers and disregard lack of such data on axial loading. This in turn leads to more undesirable situations. For graphical illustration of stress incurred in U-bolt see the Figure 4 below.

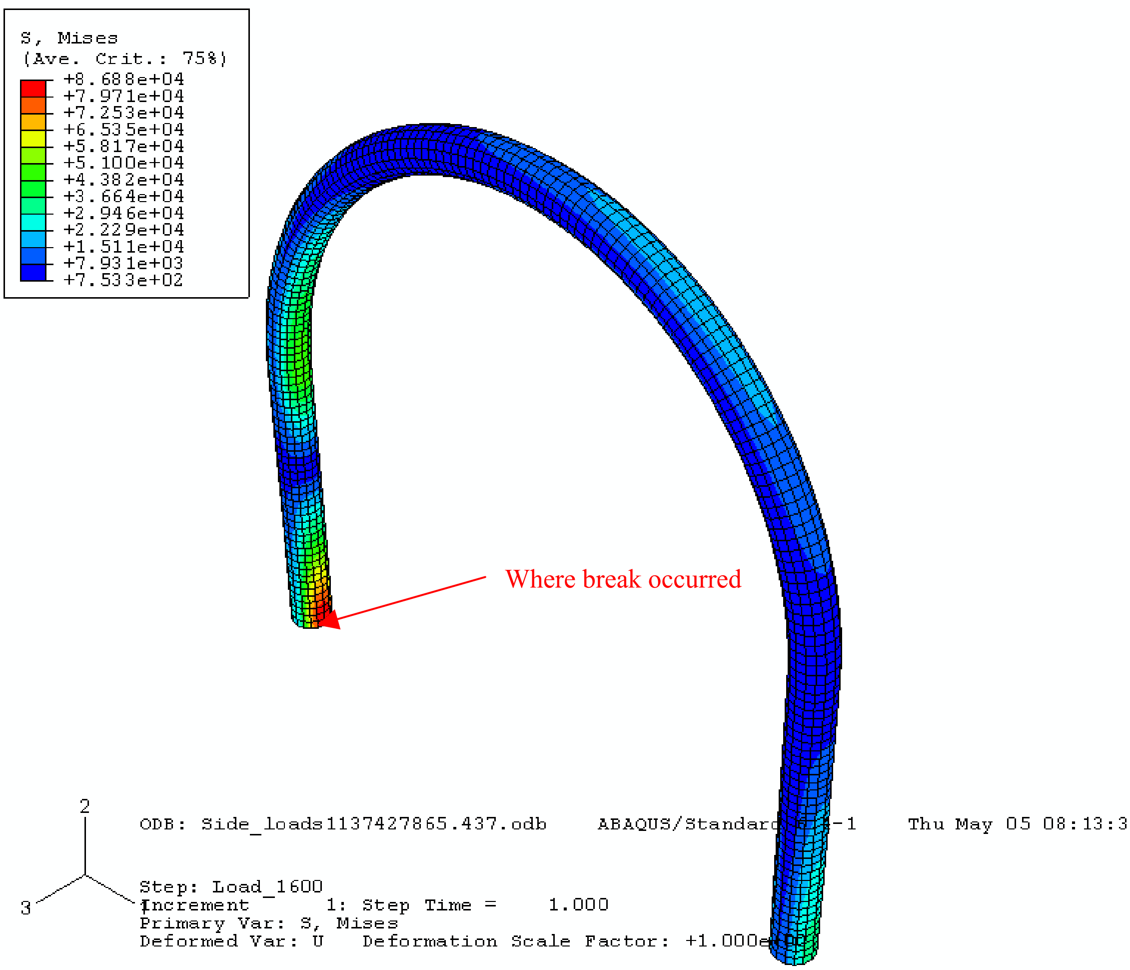

Figure 4 - Actual induced stress

3.2 Required results

For safe application of new U-bolts and assessment of existing applications it is necessary to establish realistic capacity values for all sizes of U-bolts in vertical, lateral and axial directions of applied loads. Those reliable values will be placed in our internal standards and maintenance procedures to prevent misunderstanding, misapplications and U-bolt failures.

3.3 Methodology

General method of getting answers to all our questions is Finite Element Analysis. Loads are applied to the accurately modelled U-bolts and required answers are acquired through the individual analysis of each one of them.

Capacity problems are being resolved at the present time. Methodology for this problem is more complicated because of multiple requirements dictated by multiple Codes. That is caused in turn by the fact that U-bolts were installed in systems of all nuclear and non-nuclear classes. That means that requirements of NT, B31.1 and MSS SP-58-2002 should be followed. It was reasonable to develop method that would satisfy all of the involved Codes. Reasoning behind this method was as follows:

Common material used for U-bolt manufacture was per our internal Standard and manufacturers' information A36.

Comparison of allowable stresses:

Class 1 – Sm = 19.3 ksi at 70 deg. F. and 17.7 ksi at 600 deg. F.

Class 2/3 – S = 14.5 ksi at 70 deg. F. and 14.5. ksi at 600 deg. F.

Class 6 – Sa = 16.6 ksi at 70 deg. F. and 16.6 ksi at 600 deg. F.

Because pipe is in contact with U-bolt it was decided to check the local effect of the contact on pipe. As most commonly (prevalent) pipe material used the carbon steel SA 106 Gr.B was selected.

Comparison of allowable stresses for pipe:

Class 1 – Sm = 20.0 ksi at 70 deg. F. and 17.3 ksi at 600 deg. F.

Class 2/3 – S = 15.0 ksi at 70 deg. F. and 15.0 ksi at 600 deg. F.

Class 6 – Sa = 15.0 ksi at 70 deg. F. and 15.0 ksi at 600 deg. F.

Yield strength was considered to prevent any deformations.

Yield Strength for U-bolt is:

Sy = 36.0 ksi at 70 deg. F. and 26.6 ksi at 600 deg.F.

Yield Strength for pipe is:

Sy = 36.0 ksi at 70 deg. F. and 25.9 ksi at 600 deg.F.

Von Mises criterion was used as the "common sense" check and because it is energy based it was compared with Yield and 70% of the Ultimate Stresses.

It was the final check of appropriate stress levels in the U-bolt under load.

Ultimate Strength for U-bolt is:

Su = 55.0 ksi at 70 deg. F. and 55.0 ksi at 600 deg.F.

Ultimate Strength for pipe is:

Su = 60.0 ksi at 70 deg. F. and 60.0 ksi at 600 deg.F.

Physical properties for U-bolts and pipes were taken at temperature of 600 deg. F. as the highest temperature that U-bolts are applied in our plant. This was conservative measure. Those properties were applied to F. E. A. models of U-bolts and pipes.

$E = 29.5 \times 10^6$

$\nu = 0.29$

Density = 0.279 lbs/in^3

After applying those properties and getting computed results we would like to develop set of criteria that would cover requirements of all classes in range of temperatures usually encountered in our station. Because values of allowable stresses and modulus of elasticity become lower at higher temperatures values at temperature of 600 deg. F. was chosen as a conservative measure.

Rules of ASME Section III, Subsection NF were used to calculate stress levels induced in loaded U-bolts and to compare those stresses against allowable values. Per NF-3143 (1) elastic analysis should be based on maximum stress theory in accordance with rules of NF-3300. Per table NF-3623 (b) – 1 allowable stresses are:

Allowable = Ks/Kv * Sm/Sa where:

Ks = coefficient for tensile and bending stresses

Kv = coefficient for shear stresses

Ks = 1.0 for Service Level A and Kv = 1.0 for Service Level A

Ks = 1.33 for Service Level B and Kv = 1.33 for Service Level B

Ks = 1.5 for Service Level C and Kv = 1.5 for Service Level C

Derivation of stress intensities per NF-3222 is:

$S_{12} = \sigma_1 - \sigma_2$

$S_{23} = \sigma_2 - \sigma_3$

$S_{31} = \sigma_3 - \sigma_1$

Value of S used for comparison with allowable value is largest absolute value of S_{12}, S_{23} and S_{31}.

Of course for Class 6 (non-nuclear) piping straight comparison with allowable values should be observed.

As a practical measure a border value of the Yield Stress will be observed because U-bolts are located in many inaccessible areas and are too numerous to watch closely and frequently. Because yield is directly related to expanded energy von Mises criterion will be used for comparison with Yield Threshold.

Because this approach requires collecting large amount of data and numerous comparisons within multiple data sets, spreadsheet was developed to simplify this process. For example of spreadsheet see the Figure 5 below.

where:

s_1 = stress component in direction 1

s_2 = stress component in direction 2

s_3 = stress component in direction 3

cells contain formula do not change

$S_{12} = s_1 - s_2$

$S_{23} = s_2 - s_3$ S = largest absolute value of S_{12}, S_{23} and S_{31}

$S_{31} = s_3 - s_1$

Values for U-bolts at 600deg. F

Model	**Load** [lbs]	**Direct.** {side/vert}	**s_1** [psi]	**s_2** [psi]	**s_3** [psi]	**v. Mises** [psi]	**S_{12}** [psi]	**S_{23}** [psi]	**S_{31}** [psi]	**S** [psi]	**Sm** [psi]	**Sa** [psi]	**Sy** [psi]	**Su** [psi]	0.7 * Su [psi]
U0_5	*{test}*	side	12375	8964	-4375	38560	3411	13339	-16750	13339	17300	15000	26600	55000	38500
U0_5	*{test}*	vert	23875	17500	-8975	38050	6375	26475	-32850	26475	17300	15000	26600	55000	38500

... continuation ...

Model	**Load** [lbs]	**Direct.** {side/vert}	passed Sm?	passed Sa?	passed Sy?	passed Su?	passed 0.7*Su?	Class 1 check	Class 2/3 check	Class 6 check	Yield check	All Conditons check	***Common sense check against 0.7 * Su*** **von Mises check**
U0_5	*{test}*	side	PASSED	PASSED	PASSED	PASSED	PASSED	PASSED	PASSED	PASSED	PASSED	TRUE	NO!
U0_5	*{test}*	vert	NO!	NO!	PASSED	PASSED	PASSED	NO!!	NO!!	NO!!	PASSED	FALSE	PASSED

Figure 5 - Example of results collection spreadsheet

3.4 Present situation and future progress

At the present moment analytical work is progressing. It takes multiple runs and iterations before proper values for all classes and cases are established for one U-bolt size. At the same time this work does not have high priority and can not take precedence in front of other pressing problems. That of course means very slow progress. When finished, dependable values will be issued in Controlled Document, relevant manuals and internal standards will be modified to provide for use of proper values in all of maintenance and design work.

4.0 ACKNOWLEDGEMENTS

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